International Journal of Geology, Earth & Environmental Sciences ISSN: 2277-2081 (Online)
An Online International Journal Available at http://www.cibtech.org/jgee.htm
2013 Vol.3 (2) May-August, pp.68-76/Sharma and Sarma

Research Article

MICROSTRUCTURAL STUDY AND STRAIN HISTORY OF MESOPROTEROZOIC AUGEN GNEISS OF LOHIT DISTRICT, ARUNACHAL HIMALAYA, INDIA

Rupsikha Sharma and *K.P. Sarma
Department of Geological Sciences, Gauhati University, Guwahati-781014, Assam
**Author for Correspondence*

ABSTRACT

The arcuate nature of the Himalayan belt from Peshawar of Pakistan to Mishmi block of Arunachal Himalaya is one of the world's most active and seismically sensitive tectonic belts of continent-continent collisional tectonism between Indian and Eurasian plates. The study area lies in the Parasukund-Tohangum-Tidding-Hayuliang-Walong geotransect of Mishmi Himalaya and a few notable thrust systems are delineated eg. Mishmi thrust, Lalpani thrust, Tidding thrust, Lohit thrust and Walong thrust. Parasukund of Lohit district of Arunachal Pradesh is one of the holy places of NE India. It is located in the southern bank of the river Lohit. Geologically Parasukund belong to Lesser Himalayan Crystalline belt (Proterozoic augen gneiss) tectonically overlie the relatively thin Lesser Himalayan Sedimentary Sequence with SW thrusting movement. A huge slice of augen gneiss is observed on the Lohit riverbed which acts like an island and traditionally this slice of augen gneiss is considered as an axe of Parasuram. Amphibolites, quartzite, diorite gneiss and pegmatite are interlayered with most extensively sheared augen gneiss. Three phases of ductile deformation are marked followed by a brittle phase producing faults of both extensional and contractional habits. Ultramafic lenses and leucogranite sheets are enclosed within the augen gneiss and they are pinching out in the X-direction of tectonic transport (SE). Minor folds of second deformation show top to the SW vergence. Microstructural behaviour of sheared augen gneiss registered multiple phases of deformation showing right and left lateral shear senses. Strain calculation from porphyroclasts and their intensity and magnitude are worked out systematically from different localities of the Lesser Himalayan Crystalline zone. NE dipping lithological layering is considered as XY plane of the strain ellipsoid. Flinn plots are suggestive of flattening field (K= 0.528) and magnitude of flattening is more towards the thrust plane. The stretching direction of mineral lineation is correlatable with the ϕ angle and the strain ratio varies from 1.72 to 2.59 in the positive field indicating rotational affinity in the field of simple shear.

Key Words: *Augen Gneiss, Lohit Himalaya, Strain Analysis*

INTRODUCTION

The Himalaya, one of the world's most active and seismically sensitive tectonic belts, is a product of continent-continent collision of the Indian and Eurasian plates. It portrays a curvilinear southerly convex disposition with a geographical extension for 2500 (approx) km from western syntaxial bend at Nanga Parbat ($33^0$15'N: $74^0$36'E) to eastern syntaxial bend at near Namcha Barwa ($29^0$37'N: $95^0$15'E) or in Indian context Lohit Himalaya. Out of the three sectors of Himalaya namely western Himalaya, central Himalaya and eastern Himalaya, the present study area belongs to eastern Himalaya and categorically falls under Mishmi block of Arunachal Himalaya (erstwhile Lohit Himalaya).

The area is a part of Mishmi block mostly along Lohit river valley in the Parasukund-Tidding-Hayuliang geotransect (Figure1). The entire geotransect is a transaction through Mishmi thrust, Lohit thrust, Tidding suture zone and a part of Lohit Granitoid Complex of Arunachal Pradesh, India.

Parasukund or Brahmakund of Lohit District of Arunachal Pradesh is one of the holy places of NE India where people from different parts of the country used to visit almost all throughout the year, specifically during second half of January (Makarsankranti). There is a common belief that if you take bath in the Parasukund, you will be made free from all types of sin and mental agony. The name Parasukund or logically Brahmakund is given after Parasuram, the 6th incarnation (avater) of Lord Brahma (Sarma *et al.*, 2006). Geologically Parasukund belong to Lesser Himalayan Crystalline belt (Proterozoic augen gneiss). A huge slice of augen gneiss (Figure 2A) is observed on the Lohit river bed which acts like an island and traditionally this slice of augen gneiss is considered as an axe of Parasuram, where imprints of folds, faults, foliations and lineations are seen. The lower interface of the Mesoproterozoic augen gneiss or Tezu gneiss is marked at 1 km south of Parasukund ($27^0$52'57''N; $96^0$21'42''E) and at Tohangum ($27^0$55'10"; $96^0$19'38") while the upper interface is located at Udayak Pass ($27^0$56'01"N; $96^0$21'22"E). Within the gneissic belt interlayering of amphibolites, quartzite, diorite gneiss, leaucogranite, pegmatite and other vein rocks are found. They show intensive ductile shearing, and are affected by three phases of deformation marked by folds, foliations and lineations followed by another brittle phase producing faults of both extensional and contractional habits. Relatively thin green coloured ultramafic lenses are enclosed within the augen gneiss and they are pinching out in the direction of tectonic transport (SE) (Figure 2B). Augen gneiss is well exposed in Parasukund area .The gneiss is classified on the basis of their colour index and degree of shearing with more than 50% feldspar augens set in a fine to medium grained quartzofeldspathic matrix and 10 to 20% mafic minerals like biotite and rarely chloritised hornblende. Augen gneiss is highly mylotinised and anastomosing foliation is very common (Figure 2C). Grain size reduction and high degree of mylotinisation is increasing towards the thrust zone at lower structural level (MBT=Mishmi Thrust) than the higher structural level (MCT=Lalpani Thrust). They are associated with thinly bedded, medium grained and schistose amphibolites and quartzites. Near Hawa Pass and Parasukund view point, it is interlayered with garnetiferous leucogranite. The augen gneissic belt extends upto Udayak Pass where metasedimentary rock units marks a tectonic contact named as Lalpani Thrust (Mishra *et al.*, 2009).

Regional Geology

The Namche Barwa is a NE plunging antiform bordered by dextral shear zone to the eastern side and sinistral shear zone to the western side (Ding *et al*., 2001). Burg and Podlachikov (1998) have suggestd that Siang antiform (India) is a south western continuation of the Namche Barwa antiformal syntaxis. If this is the case, can we think of that the western Himalayan along Bame fault (thrust) has shifted northward as hinterland (hanging wall) and Siang antiform acts as footwall with sinistral motion? The left lateral vergence of Siang antiform and right vergence of Namche Barwa antiform is genetically related to the nearly N-S trending Bame fault. On the other hand, question arises whether Lohit Himalaya (Mishmi Block) is a continuation of western Arunachal Himalaya and joins Indo Myanmar Mobile Belt; or it stands as an independent geo unit of regional extension tectonically transported from Myanmar side and acts as tectonic linkage, tectonic umbrella or roof placed over the two pillars like E-W trending Arunachal Himalaya to the west or NNE-SSW trending IMMB to the SE (Nandy, 2001; Sarma *et al*., 2009).

Out of the major rivers of Mishmi Himalaya namely Siang, Dibang and Lohit, Lohit River represents the easternmost orographic curvature and transects the NW-SE trending Mishmi litho unit as a whole at high angle. From lower structural level to the south to higher structural level to the north, Pleistocene River Terrace (PRT) / Brahmaputra alluvium is tectonically overlain by Lesser Himalayan Sedimentary Sequence (LHSS); the latter is again thrusted by Lesser Himalayan Crystalline (LHC) or Mesoproterozoic augen gneiss. No Siwalik and Gondwana sequences are traceable along this transect although the same are mapped in the Siang sector. Singh and Chowdhary (1990) have opined that the Siwalik and Gondwana sequences are pinching out eastward. Hence, their extension is not traceable either in Dibang or Lohit sectors. Conventional Mishmi thrust (=MBT=Dibang thrust) is marked between PRT and LHSS. LHSS comprises phyllites, phylonite, quartzites, mylonites, quartz – actinolite schist and they are highly sheared and folded by multiphase deformation (Figure 2D). LHC is represented by Tezu gneiss (Roing gneiss) which includes augen gneiss, biotite gneiss, diorite gneiss and thinly bedded amphibolites, quartzite and pegmatite. Higher Himalayan Sequence (HHS) is thrusted over the metasedimentovolcanics and Proterozoic augen gneissic complex near Udayak Pass and this thrust is named as Lalpani thrust (=MCT) (Mishra, 2009; Sarma *et al*., 2011). The metasedimentary and metavolcanic rock units of the

Lohit valley are represented dominantly by amphibolites, hornblende–actinolite–chlorite schist, staurolite–kyanite bearing metapelites, carbonaceous phyllite, crystalline limestone, chlorite–actinolite schist and quartzite and vein rocks. Tiding Formation consists of tremolite – actinolite schist, marble and serpentinite bands. Huge layered sequence of ultramafics is observed in Tidding area and they are highly serpentinised (Tiding Formation of Thakur and Jain, 1975). These rock units are designated as Tidding serpentinite, a suture zone lithopackage (Nandy *et al*., 1975; Nandy, 1980) and correlated with the Mogok belt of Burma (Goosens, 1978). Leucogranite is also available in this suture zone lithopackage. Further north at higher structural level, Lohit Granitoid Complex (LGC) (granite, granodiorite, tonalite granite masses) overlie the metasedimentovolcanic rock units and conventional Lohit thrust is placed at this southern boundary of LGC (Gururajan and Choudhuri, 2007; Choudhuri *et al*., 2009; Goswami, 2011; Sarma *et al*., 20011, 2012). Gururajan and Choudhuri (2003) have studied the Lohit valley and set four large tectonic units namely Lesser Himalayan rocks, Mishmi Crystalline, Tidding Suture zone and Lohit Plutonic Complex which is an enlarged approach of Thakur and Jain (1975).

Over and all, Lohit valley geotransect has some significant similarities against a number of dissimilarities with the Dibang valley geotransect and this aspect has been delineated in detail by Sarma *et al*. (2007 and 2012). The Lohit Batholith or LGC is studied by Goswami (2011 and 2013) and he sets forth deformational episodes of the LGC as well as emplacement of the leucogranite phase. The two feldspar thermometry is work out and it gives a temperature range of 400 ± 50^0C, which is the inversion temperature for orthoclase to microcline under high stress condition (Goswami, 2011).

Petrography

In thin sections of augen gneiss, well-developed alternate bands of felsic (quartz and feldspar) and mafic (micas) minerals are seen. It is medium to coarse grained, dominantly constituted by quartz, feldspar and micas (biotite and muscovite). The proportion of plagioclase feldspar and microcline vary considerably. Apatite, zircon, sphene, epidote and rutile occur as accessories. Development of garnet is seen mostly along the contact zones between leucogranite and augen gneiss. The mafic parts of the gneisses can be considered as mesosome and the felsic parts constitute the leucosome. Sometime leucosome part is found to criss cross the foliation of the gneiss.

Quartz occurs as both small and large grains and is highly granulated due to shearing. Smaller grains are subrounded and occur as inclusions within other minerals. The larger grains are elongated and are parallel to sub-parallel to the biotite flake defining CS_2 foliation. Plagioclase occurs as subidioblastic to xenoblastic grain. Microcline occurs as xenoclastic grain with smooth grain boundary. Biotite occurs as subidioblastic, somewhat irregular flakes and defines the CS_2 foliation. Long and narrow flakes of biotite ($Biotite_1$) form CS_2 fabric while the short and thick biotite ($Biotite_2$) is discordant to the CS_2 fabric and lie at high angle to the dominant foliation. Narrow flakes of muscovite are often interleaved with biotite and take part in the formation of CS_2 foliation. Garnet occurs as small idioblastic grain showing S_1 fabric marked by quartz and magnetite. They are highly fractured and rotated either in sinistral or dextral motion. Rarely they show sigma tail and flattened in the direction of CS_2 fabric. Magnetite, sphene, zircon, apatite, epidote are common accessories.

The common mineralogical assemblages are:

Quartz-plagioclase-muscovite-biotite-garnet-accessories;
Quartz- plagioclase-microcline-biotite-muscovite-garnet-accessories;
Quartz-plagioclase-biotite-microcline-muscovite-accessories.

Structure and Microstructure

Both mesoscopic and microscopic structural fabrics are worked out from Mesoproterozoic augen gneiss and their habits and geometry are almost similar to the adjacent Roing gneiss of the Mishmi block. Stratigraphically, Roing gneiss is the strike extension of the Tezu gneiss. The protolith of the augen gneiss is porphyritic granite. The enclosed mafic enclaves mark the imprint of first phase folding which is associated with planar fabric (S_1) and they are treated traditionally as the Prehimalayan structure. During Himalayan orogeny, the rock is highly sheared; mylonitised and porphyries become stretched to augen shapes showing rotational movement either with sinistral or dextral senses (Figures 2C, 2I). Such sheared mylonotic planes are designated as CS_2 of second deformation representing Synhimalayan orogeny (Figure 2E). F_2 is coaxial to F_1 and marked as tight to isoclinal fold associated with axial planar (CS_2) foliation (Figure 2D). In mesoscopic and microscopic scales, CS_2 is the most pervasive and regional fabric acting as reference surface where later deformational imprints are registered. CS_2 is highly crenulated by F_3 folding (Figure 2F) and subsidiary shears (CS_3) transects CS_2 at high angle. Small scale folds (F_2) show top to the SW shear sense while F_3 asymmetric folds are marked as top to the NW and / or SE vergence (Figures 2B, H). Relatively thin sheets/discontinued layer of leucogranite show fish head garnet with elongation direction parallel to the CS_2 foliation (Figure 2G). The axial planar orientation of F_3 is marked on the photomicrographs as top left to bottom right shear sense (Figure 2H). Both F_2 and F_3 phases are considered as Synhimalayan orogeny with NE-SW compressional tectonism followed by NW-SE shortening respectively. The generalised orientation of litholayering of the Mishmi block is NW-SE and their regional pervasive shear foliation is also parallel to the litholayering. F_1 and F_2 folds are considered as coaxial while F_3 superposed over F_2 developed dome and basin structures in the mesoscopic scale. Fourth phase of deformation is manifested by brittle phase with the formation of faults, kinking and large scale fracturing. Their orientation varies from NNE to NNW. No mineral growth and ductile flow is observed during this phase and is correlatable with the post Himalayan phase.

Strain Analysis

Different techniques were developed to compute strain from various strain markers. Out of different strain markers such as oolites, alterating spots radiolarian cells, worm burrows, amygdules, ribbon quartz and augens in gneisses which act as strain markers to estimate finite strain in rocks, the present discussion is related to strain measurements of augens in augen gneiss of Lohit valley Complex of Mishmi block. Initial shape of the augens was considered to be euhedral but size of the augens was not known. If both the augens and the matrices indicate same viscosity they may be treated as passive markers but in the present context viscosity differences are observed. Hence, passive markers aspect is a doubtful parameter to be dealt with while estimating the strain analysis of the augens in augen gneiss. If the initial shape of the augen is considered as anhedral, the final shape of the markers after deformation would not represent strain ellipsoid but would depend upon the finite strain and initial shape and orientation of the augens. Such problems of non spherical markers was initiated by Ramsay (1967) and formulated Rf / ϕ method which was later on enlarged and elaborated by many workers like Dunnet (1969), Ramsay and Huber (1983), Lisle (1985) and many references therein. There are different methods available for strain analysis, out of which three methods are adopted for the present study namely (1) Flinn plots (Flinn 1962), (2)R_f / ϕ plots (Ramsay 1967; Dunnet, 1969; Dunnet and Siddan, 1971), (3) Fry method (Fry, 1978, 1979; Hanna and Fry, 1979). These plots are prepared using the software 'Sixstrain' developed by P.P.Roday (2003). Treagus and Treagus (2001) have suggested that if the strain markers are competent in comparison to incompetent matrix, the axial ratio will be 3:1 or more which is higher than that of a circular marker in a same viscous media. In the present context, the shape parameter of the augen is assumed to be euhedral with approximately 2:1 irrespective of their sizes; thereby viscosity parameter is to be considered as nearly same.

Different measurement techniques are used in the field such as:

(1) The attitude of the S- plane is measured with geographic coordinates and orientation of the north.

(2) Sharp boundaries between augens and matrices are taken care of and where such boundary is diffused the measurements of length, breadth is not carried out.

(3) Length and breadth of all individual augens are measured with measuring tape.

(4) The orientation of the long axis is marked with respect to orientation of the planar fabrics in the matrix either in the clockwise or in the anticlockwise directions. The dextral rotation with respect to reference surface is considered as negative ϕ and sinistral rotation is positiveϕ.

(5) Measurements are made specifically in the regions where higher order population or concentration of augens is noted.

Research Article

Taking into consideration of all the above parameters, measurements of strain markers are made from different localities from Parasukund to Tohangam and further to Udayak Pass. The moderately NE dipping foliation plane or lithological layering (= bedding plane) is considered as XY plane of the strain ellipsoid syngenetic to sub Himalayan orogeny during second phase of deformation (D_2). Such assumption is at par with Ramsay and Huber (1983). X direction of strain ellipse is maked as long direction of the augens. X and Y directions are marked as near horizontal while Z direction is vertical. Most of the measurements are made on XZ and YZ planes. Measurements on YZ plane are feasible because of oblique joint planes. In augen gneiss most of the feldspar augens either show right vergence or left vergence and they make angular relationship with the matrix foliation (X- direction). While selecting the sites for measurements of length and breadth of the augens relatively smooth and clean surfaces are chosen.

Sometimes transparent overlays are also made use of with specific geographic orientation, reference line and coordinates. Photographs are also taken with scale and they are measured in the lab for computational work.

RESULTS AND DISCUSSION

The generalised trend of the Arunachal Himalaya upto Bame fault from Bhutan is roughly NE-SW while the generalised strike of the Lohit Himalaya or Mishmi Block is NW-SE. Such deviation of the generalised strike cum trend of the lithological layering may be a cause and effect of dextrally moving Bame fault followed by sinistrally moving thrusted block of Mishmi Himalaya (Sarma *et al*., 2009).

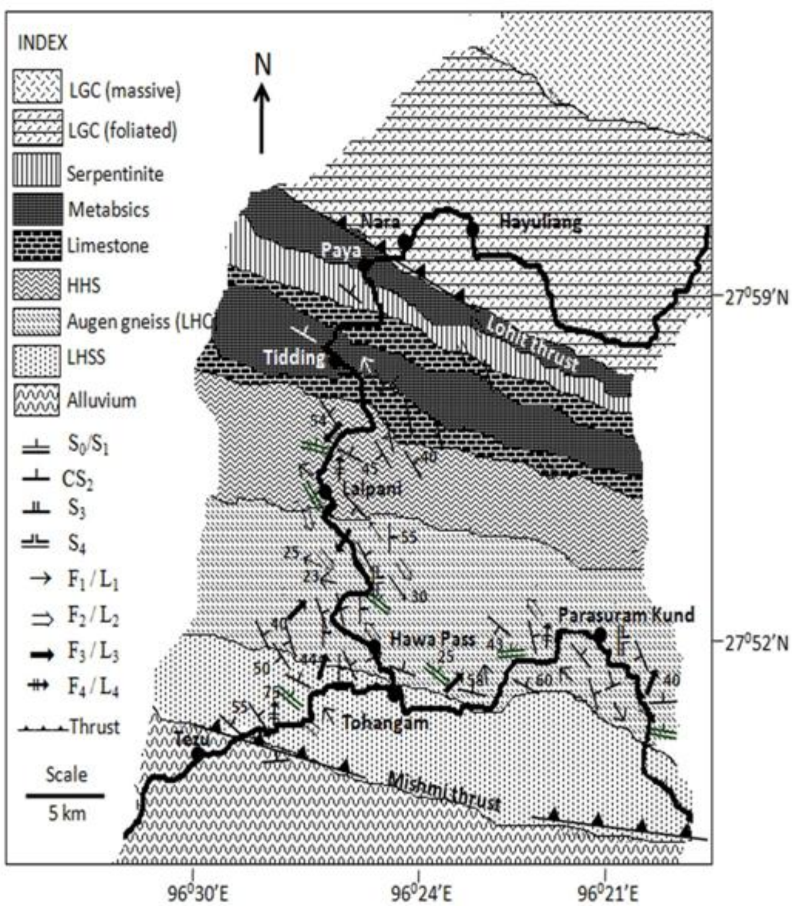

Figure 1: Generalised lithological cum structural map of the study area

Research Article

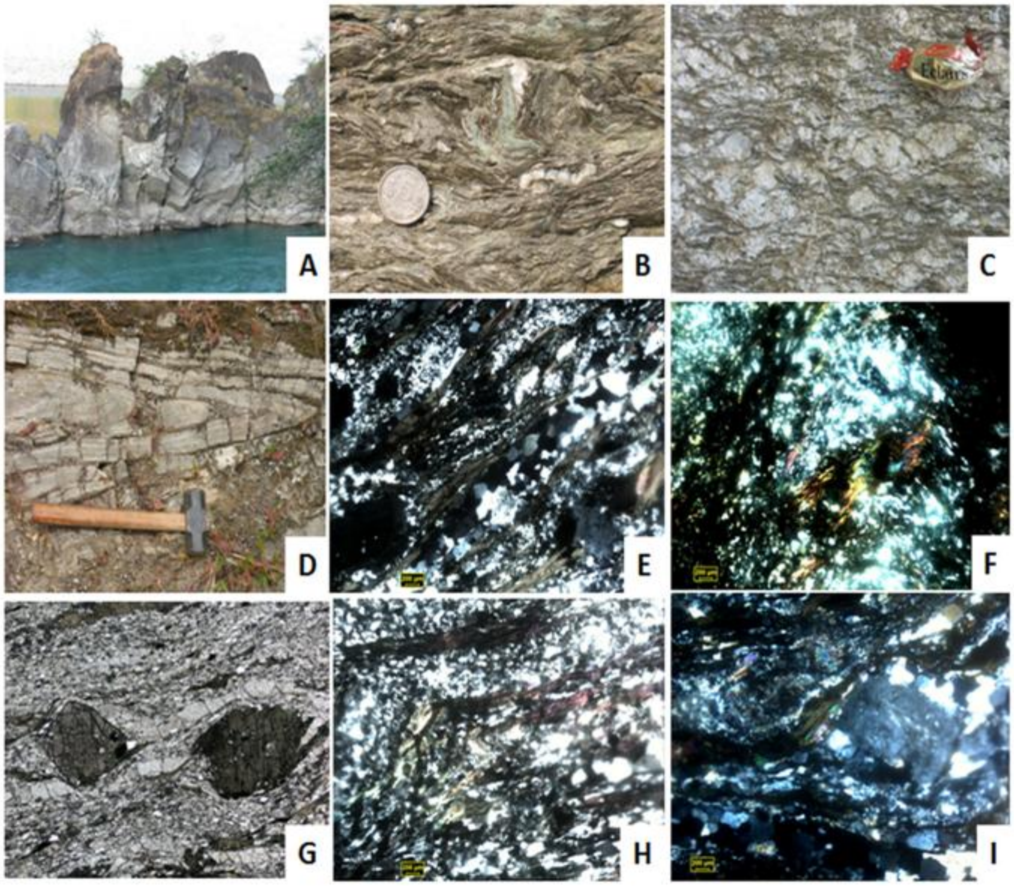

Figure 2:
A) An isolated slice of augen gneiss observed in Lohit river bed at Parasukund.
B) A tectonic lense of ultramafic rocks portraying right vergence asymmetric F_3 fold enclosed within most ductile augen gneissic host. Location: near Parasukund area.
C) Proterozoic augen gneiss showing CS_2 anastomosing foliation and rotation of the porphyroclasts from Tohangum area.
D) Tightly appressed F_2 fold in Lesser Himalayan Sedimentary Sequence from Tohangam area.
E) Photomicrograph of augen gneiss showing development of CS_2 foliation.
F) Photomicrograph showing development of crenulations (F_3) in CS_2 mylonitic foliation.
G) Photomicrograph of fish head porphyroclasts in leaucogranite.
H) Photomicrograph showing left vergence closed F_3 fold in mylonitic gneiss.
I) Photomicrograph exhibiting sinistral rotation of feldspar augen and deflected CS_2 foliation round the porphyroclast.

The overall geology of the Mishmi Himalayan block is least understood as compared to the Western Arunachal Himalaya. Out of the two notable valleys of the Mishmi Block namely Dibang Valley and Lohit valley the tectonostratigraphic sequences of the Dibang valley is studied recently by a few workers (Sarma *et al.*, 2009 and 2012) but in case of Lohit valley although few workers are working on various aspects of geology like petrology, petrochemistry, structural geology and stratigraphy but no significant works on structural aspect are done. The present study is a part of the works leading to the polydeformational history of the Proterozoic augen gneiss and their strain analysis. The traditional Mishmi thrust and Lohit thrust are marked and they represent a structural discontinuity, lithologic variation and stratigraphic dissimilarity but nowhere such stratigraphic hiatus is marked by the formation of conglomerates. Four phases of deformations are established; the first and second phases are nearly coaxial with NW-SE trend whereas the third phase of deformation transects the lithological layering cum pervasive foliation at high angle trending NE-SW direction. Fourth phase was of brittle nature. The different lithosequences are thrust bounded namely Mishmi Thrust at the lower reaches near Parasukund-Tohangum areas and Lohit Thrust at the upper reaches near Paya. Flinn diagrams show plots in the flattening field (k= 0.528) (Figures 3A, 3B). Fry diagrams are prepared and the strain ratio varies from 1.72 to 2.59 in positive field (anticlockwise) (Figures 3C, 3D). ϕ angle varies from nearly parallel to the reference line to 33^0 and such rotation is a clear indicative of the simple shear mechanism. In Rf / ϕ plot, the apparent strain ratio also varies within a narrow angle 2.11 to 2.34 in XZ plane (Figures 3E, 3F). Hence the initial tectonic flow in NW-SE direction is being transposed by later deformation showing the effect of rotational movement of the incremental strain axis in sinistral motion during D_3 deformation. The presence of minor faults with N-S axial trend probably marks the last stage of the deformational phase of Lohit Himalayan block.

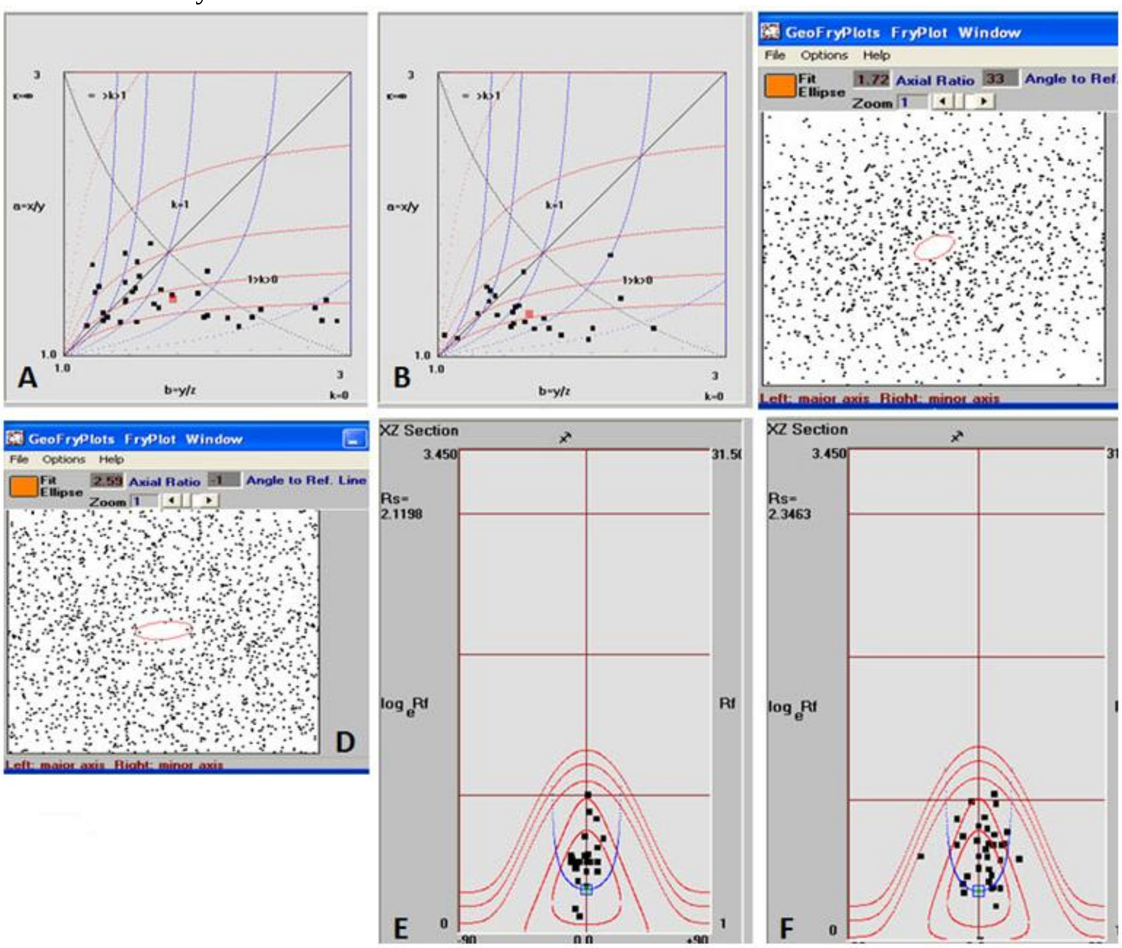

Figure 3: A), B) Flin diagrams prepared from augens gneiss. Location: Parasukund and Tohangam areas respectively. C), D) Fry plots from the same areas as in Figures 3A and B. E), F) Rf/ϕ plots from strain markers of augen gneiss from Parasukund and Tohangam areas respectively.

ACKNOWLEDGEMENT
The authors are thankful to the Department of Geological Sciences, Gauhati University, Guwahati for providing facility to carry out the work. One of the authors (Rupsikha Sharma) is thankful to the Ministry of Science and Technology, Department of Science and Technology, Government of India for providing

Research Article

financial assistance in the form of INSPIRE Fellowship/2012/451 (IF120484). Thanks are also due to Ms. Nandita Mazumdar for her help during the fieldwork.

REFERENCES

Burg JP and Podlachikov Y (1998). Bending of syntaxes, consequences. *Special issue on the 13th Himalayan - Karakoram – Tibet International workshop (April 20 – 23, 1998), Geological Bulletin, University of Peshwar, Pakistan* **31** 39 – 41.

Choudhuri BK, Gururajan NS and Singh RKB (2009). Geology and structural evolution of the eastern Himalayan Syntaxis. *Himalayan Geology* **30**(1) 17-34.

Ding L, Zhong D, Yin A, Kapp P and Harrison TM (2001). Cenozoic structural and metamorphic evolution of the Eastern Himalayan syntaxis (Namche Barwa). *Earth Planetary Science Letters* **192** 423–438.

Dunnet D (1969). A technique of finite strain analysis using elliptical particles. *Tectonophysics* 7(2) 117–136.

Flinn D (1962). On folding during three-dimensional progressive deformation. *Quarterly Journal of the Geological Society of London* **118** 385–433.

Fry N (1978). Construction and computation of 3-D progressive deformation. *Journal of Geological Society of London* **135** 291–305.

Fry N (1979). Random point distributions and strain measurement in rocks. *Tectonophysics* **60** 89–105.

Goosens PJ (1978). The metallogenic provinces of Burma: their definitions, geologic relationships and extension into China, India and Thailand; In: *Third Regional Conference on Geology and Mineral Resources of South East Asia* (edited by Nutalaya, P.), Bangkok **3** 431-492.

Goswami TK (2011). Collision induces deformation of the Trans Himalayan Lohit Batholith, Arunachal Pradesh, India. *Memoir Geological Society of India* **77** 19-31.

Goswami TK (2013). Geodynamic significance of leucogranite intrusions in the Lohit Batholith near Walong, Eastern Arunachal Pradesh, India. *Current Science* **104**(2) 229–234.

Gururajan NS and Choudhuri BK (2003). Geology and tectonic history of the Lohit Valley, Eastern Arunachal Pradesh, India. *Journal of Asian Earth Science* **21** 731-741.

Gururajan NS and Choudhuri BK (2007). Geochemistry and tectonic implications of the Trans Himalayan Lohit Plutonic Complex, Eastern Arunachal Pradesh. *Journal of Geological Society of India* **70** 17-33.

Hanna S and Fry N (1979). A comparison of methods of strain determination in rocks from SW Dyfed (Penbrokeshire) and adjacent area *Tectonophysics* **5** 315–319.

Lisle RJ (1977). Estimation of the tectonic strain ratio from the mean Shape of deformed elliptical markers. *Geologie en Mijnbouw* **56** 140–144.

Mishra DK (2009). Litho-tectonic Sequence and their Regional Correlation along the Lohit and Dibang Valleys, Eastern Arunachal Pradesh. *Journal of Geological Society of India* **73** 213-219.

Nandy DR (1980). Tectonic patterns in northeastern India. *Indian Journal of Earth Science* **7** 103-107.

Nandy DR (2001). Geodynamics of northeastern India and the adjoining region. *Abc publication, Kolkata* 209.

Nandy DR, Mullick BB and Murthy MVN (1975). Geology of the NEFA Himalayas: Recent geological studies in the Himalayas. *Geological Survey of India Miscellaneous Publication* **24**(1) 91-114.

Ramsay JG and Huber MI (1983). The Technique of Modern Structural Geology **1**. Strain analysis. *Academic Press, London* 400.

Ramsay JG (1967). Folding and fracturing of rocks. *New York: McGrow Hills* 568.

Roday PP (2003). Windows 32-Bit Platform Software for plots to display the finite strain data. *Journal Geological Society India* **62** 36-42.

Sarma KP, Konwar P, Devi NR and Nandy S (2006). Geology in and around parasukund (Brahmakunda) of Lohit district, Arunachal Pradesh, India. *Journal of Geoscience* **11** 68-71.

Sarma KP, Nandy S, Devi NR and Konwar P (2007). Dibang and Lohit valley geotransects of Arunachal Pradesh: Some constraints. *Current trends of research in Science and Technology, Assam Science Society* **8** 31 – 40.

Sarma KP, Bhattacherjee S, Nandy S, Konwar P and Mazumdar Nandita (2011). Thrust bound lithounits of Western and Eastern sectors of Arunachal Himalaya, India: An integrated approach of correlation. *Memoir Geological Society of India* **77** 33-41.

Sarma KP, Nandy S, and Mazumdar Nandita (2012). Structural studies of the Mishmi Block in poarts of Dibang Valley of Arunachal Himalaya, Northeast India. *International Journal of Geology, Earth and Environmental Sciences* **2**(3) 43 – 56 [online] Available: http://www.cibtech.org/jgee.htm.

Sarma KP, Nandy S, Devi NR, Konwar P (2009). Is Mishmi Block a Tectonic Roof? Some Observations. *Magmatism, Tectonism and Mineralization,* (Ed. S. Kumar), Macmilan Publishers India Ltd., New Delhi, India 167-178.

Singh S and Chowdhary PK (1990). An outline of the geological framework of the Arunachal Himalaya. *Journal of Himalayan Geology* **1**(2) 162-166.

Thakur VC and Jain AK (1975). Some observations of deformation and metamorphism in the rocks of some parts of Mishmi Hills, Lohit district, (NEFA), Arunachal Pradesh. *Himalayan Geology* **5** 339–364.

Treagus SH and Treagus JE (2001). Effects of object ellipticity on strain, and implications for clast – matrix rocks. *Journal of Structural Geology* **23** 601 – 608.